



# Thermodynamics

NEW YORK STATE SCIENCE OLYMPIAD

LAKE ERIE/NIAGARA 2018-2019 INVITATIONAL COMPETITION

DECEMBER 8, 2018 - BUFFALO STATE COLLEGE

**Instructions:** This booklet contains the written test portion of the event. Do not open this book until instructed to do so by the event supervisor.

You may use any references within a single three-ring binder, provided they are attached using the rings. You may use two stand-alone calculators of any type, but cell phones may **not** be used as calculators and must remain **OFF** (not on vibrate or silent) for the duration of the event.

**All answers to this test must be marked on the included answer sheet.** Only answers marked on this sheet will be scored. **Please write your team name and number on this page and your answer sheet.** If you choose to detach any pages from this test booklet, please write your team name and number on those pages as well.

Point values for each question are indicated. You may not finish the test in the allotted time, thus, you are encouraged to complete the test in any order that you choose.

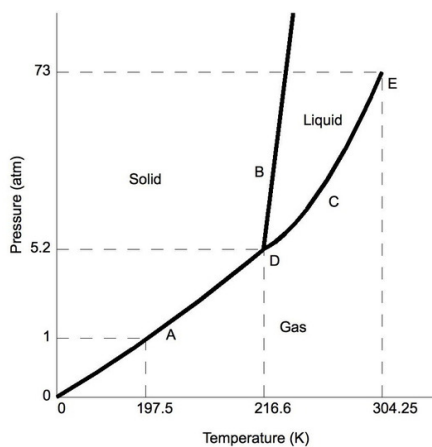
Team name: \_\_\_\_\_ Team number: \_\_\_\_\_

Members: 1. \_\_\_\_\_ 2. \_\_\_\_\_

**MULTIPLE CHOICE:** Choose the one alternative that best completes the statement or answers the question. (2 pt each)

- One of the primary contributions of Joseph Louis Gay-Lussac was the discovery that
  - the pressure of a gas tends to increase as the volume of its container decreases.
  - the pressure of an enclosed gas is directly proportional to its temperature.
  - heat is a form of motion.
  - radiant heat is transmitted as an electromagnetic wave.
- Which of the following discovered the relationship between heat and mechanical work?
  - Rudolf Clausius
  - James Clerk Maxwell
  - Jacques Charles
  - James Prescott Joule
  - Joseph Black
- Which of the following determined the connection between entropy and molecular motion?
  - Sadi Carnot
  - Robert Boyle
  - Erwin Schrödinger
  - Daniel Bernoulli
  - Ludwig Boltzmann
- Temperature measures heat energy.
  - True
  - False
- What is  $70^{\circ}\text{F}$  in Kelvin?
  - 21 K
  - 158 K
  - 252 K
  - 294 K
  - 343 K

- Which unit is defined as the energy needed to raise the temperature of 1 gram of water through  $1^{\circ}\text{C}$ ?
  - Joule
  - Calorie
  - British thermal unit
  - Therm
  - Watt
- The phase diagram for carbon dioxide is shown below. If  $\text{CO}_2$  is cooled from  $0^{\circ}\text{C}$  to  $-100^{\circ}\text{C}$  at 1 atmosphere of pressure, which process occurs?
  - Freezing
  - Melting
  - Condensation
  - Sublimation
  - Deposition



- Freezing
  - Melting
  - Condensation
  - Sublimation
  - Deposition
- Which type of heat transfer occurs through electromagnetic waves?
    - Radiation
    - Natural convection
    - Forced convection
    - Conduction

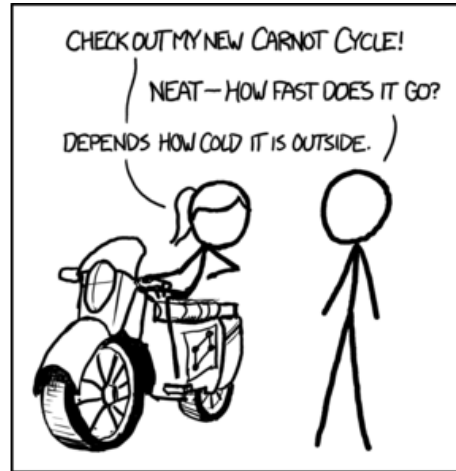
**SHORT ANSWER AND CALCULATIONS:**  
**Answer the following questions on your answer sheet. Show all work on your answer sheet.**

9. 4 kg of water at 25°C and 2 kg of ice at 0°C are mixed inside an insulated, but not airtight, container.
- (5pt) What is the final temperature?
  - (1pt) Is there any ice left?
  - (3pt) What is the change in entropy of only the water as it cooled down?

Note: the specific heat of water at constant pressure is 4186 J/(kg K) and the latent heat of fusion of water is 334 kJ/kg.

10. A 3 m<sup>3</sup> tank of hydrogen at 100 kPa and 300 K is attached to a hydrogen supply line. The supply line is at a pressure of 500 kPa and temperature of 400 K. Hydrogen then slowly enters the tank. You may assume that hydrogen behaves as an ideal gas. Hydrogen has an ideal gas constant of  $R = 4124 \text{ J}/(\text{kg K})$ .
- (2pt) What is the initial mass of hydrogen in the tank?
  - (3pt) If 1.0 kg of hydrogen is added to the tank from the supply line and 300 kJ of energy is lost in the process, what is the final temperature in the tank? Note: You may assume that the specific heat at constant volume of hydrogen is 10.3 kJ/kg across the range of temperatures in this problem.
  - (2pt) What is the final pressure in the tank?
  - (3pt) What is the change in internal energy of the tank?
11. (2pt) A square silicon chip of width  $w = 5 \text{ mm}$  and thickness  $t = 1 \text{ mm}$  is mounted in a substrate such that there is no heat loss from its side and bottom surfaces. The top surface is exposed to a coolant. The thermal conductivity of the chip is 200 W/(m K). If 5 W is being dissipated from the chip, what is the temperature difference between its top and bottom surfaces?

12. (2pt) Why would the maximum possible speed depend on the outside temperature?



13. (3pt) Is it possible for a heat engine with an efficiency of 80% to operate between thermal reservoirs at 300 K and 1000 K?
14. (3pt) What is the irradiance on a 0.0603 m<sup>2</sup> sheet of paper held normal to a 60 W light source located 2 m away?
15. (7pt) Air is contained in a piston-cylinder device and undergoes the following four processes:
- 1-2 Isentropic compression from 100 kPa and 300 K to 1 MPa
  - 2-3 Constant pressure heat addition
  - 3-4 Isentropic expansion to 750°C
  - 4-1 Constant pressure heat rejection
- Assuming ideal gas for air and the following constant properties, complete the table in your answer booklet.
- $c_v = 0.718 \text{ kJ}/(\text{kg K})$   
 $c_p = 1.005 \text{ kJ}/(\text{kg K})$   
 $R = 0.287 \text{ kJ}/(\text{kg K})$   
 $k = 1.4$